Project-X Collaboration Meeting
11-12 September 2009

Front-End Issues

John Staples, LBNL

RFQ Requirements

CW RFQ required to accelerate H-minus to 2.5 MeV

Frequency of 325 MHz (or possibly 162.5 MHz)

10 mA output current into low longitudinal phase space

Transverse input emittance 0.25 pi mm-mrad, norm, rms

RFQ Characteristics

The RFQ is an electrostatically-focused FDFD strong-focusing lattice with acceleration (E_z) added as a perturbation. The energy bandwidth of the focusing lattice allows unaccelerated beam to be transported to the exit.

There will be a low-energy tail present. About 90% of the beam will be captured and accelerated to full energy.

Subsequent magnetically-focused MEBTs and DTLs get rid of the tail harmlessly: the low-energy tail will not be transported very far.

If a superconducting RF structure follows the RFQ, tail-clipping of the output spectrum may be required.

Output longitudinal emittance somewhat dependent on the current and can increase at lower current.

CW RFQs

Few have been built and operated
- proton, heavy ion: TRIUMF, GSI, IUCF, LANL

Thermal management is critical
- high wall power density
- material stress and geometric deformation
- maintaining frequency and field distribution
- managing “hot spots” in structure
- configuration of cooling fluid passages
- high-power tuner technology

Stored energy can produce spark damage

RF coupling methods: loop or iris coupler?

High-cost RF system: minimize RF requirement

LANL LEDA RFQ
being assembled

Representative RFQs

	CRITS	KOMAC	LEDA	IUCF	Proj-X 162	Proj-X 325	
Frequency	267	350	350	213	162.5	325	MHz
Injection Energy	50	50	75	20	35	30	keV
Output Energy	1270	3000	6700	700	2500	2500	keV
Current	86	23	110	1	10	10	mA
Length	147	324	800	118	385	287	cm
Length/Lambda	1.3	3.8	9.3	0.8	2.1	3.1	
Vane-Vane Voltage	78	100	102	35	90.8	64.2	kV
Peak E-field	28.8	33.1	33.6	13.8	20.7	27.6	MV/m
E-field/Kilpatrick	1.75	1.8	1.83	0.91	1.52	1.55	
Cavity Power	159	350*/417	1200	8.4*/12	155*	149*	kW
Power/Length	107	108	150	7.1	40	52	kW/m
Avg Wall Power Density	4.6	13	11.4	0.7	2.1	5.2	W/cm2
Max Wall Power Density	116.7		65				W/cm2
r_0 (transverse vane tip radius)				0.31	0.61	0.31	cm
minimum longitudinal radius				0.52	1.2	0.69	cm
Output rms Momentum Spread					0.15	0.15	percent
Output Longitudinal Emittance		0.246	0.174	0.024	0.056	0.046	MeV-Degree
Output Transverse Emittance		0.023	0.022	0.010	0.031	0.028	cm-mrad
Transmission			90	85	94	90	percent

*=Calculated

Thanks: Dale Schrage for CRITS, LEDA

Beam Dynamics Choice

RFQs designed using K-T/LANL approach with a long adiabatic buncher section. Only about 40% of the length of the RFQ is the acceleration section. This approach works well with high-current designs.

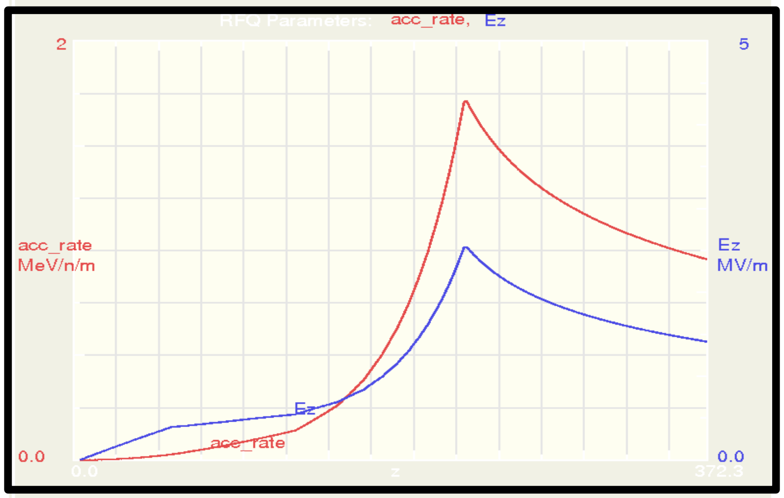
The kick-buncher design (Staples, Linac94) has several advantages for lower current designs.

Most of the RFQ is the acceleration section
The longitudinal output emittance is significantly lower
Reduced power requirement
Used on the IUCF RFQ
ADNS 40 mA deuteron RFQ design used this approach.

Accelerating Field E_z and rate of acceleration vs z.

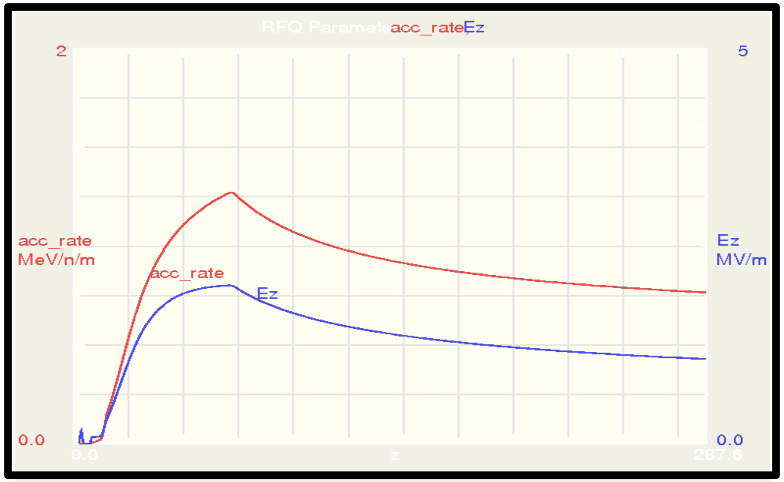
SNS RFQ

“Conventional” beam dynamics design. Most of the length is the adiabatic buncher. Both RFQs accelerate to 2.5 MeV.



Kick-buncher Design

Most of the length is the acceleration section. This results in a shorter design using lower power as the peak gradient is less even though it is 1 meter shorter.

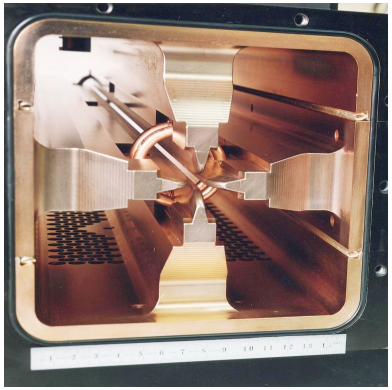


Mode Stabilization

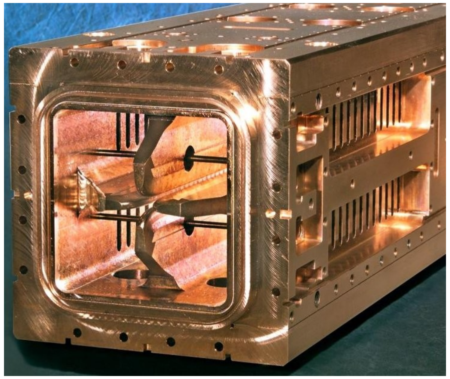
The field sensitivity to local frequency error goes as $(\mathrm{Length/wavelength})^2$.

For longer structure (greater than about 2 wavelengths), mode stabilization is recommended.

Transverse stabilization: LBNL method
Longitudinal stabilization: LANL approach



Vane Coupling Rings. Used on 4 LBNL RFQs. Not suitable for high average power.



pi-mode stabilizers. Used on SNS RFQ.

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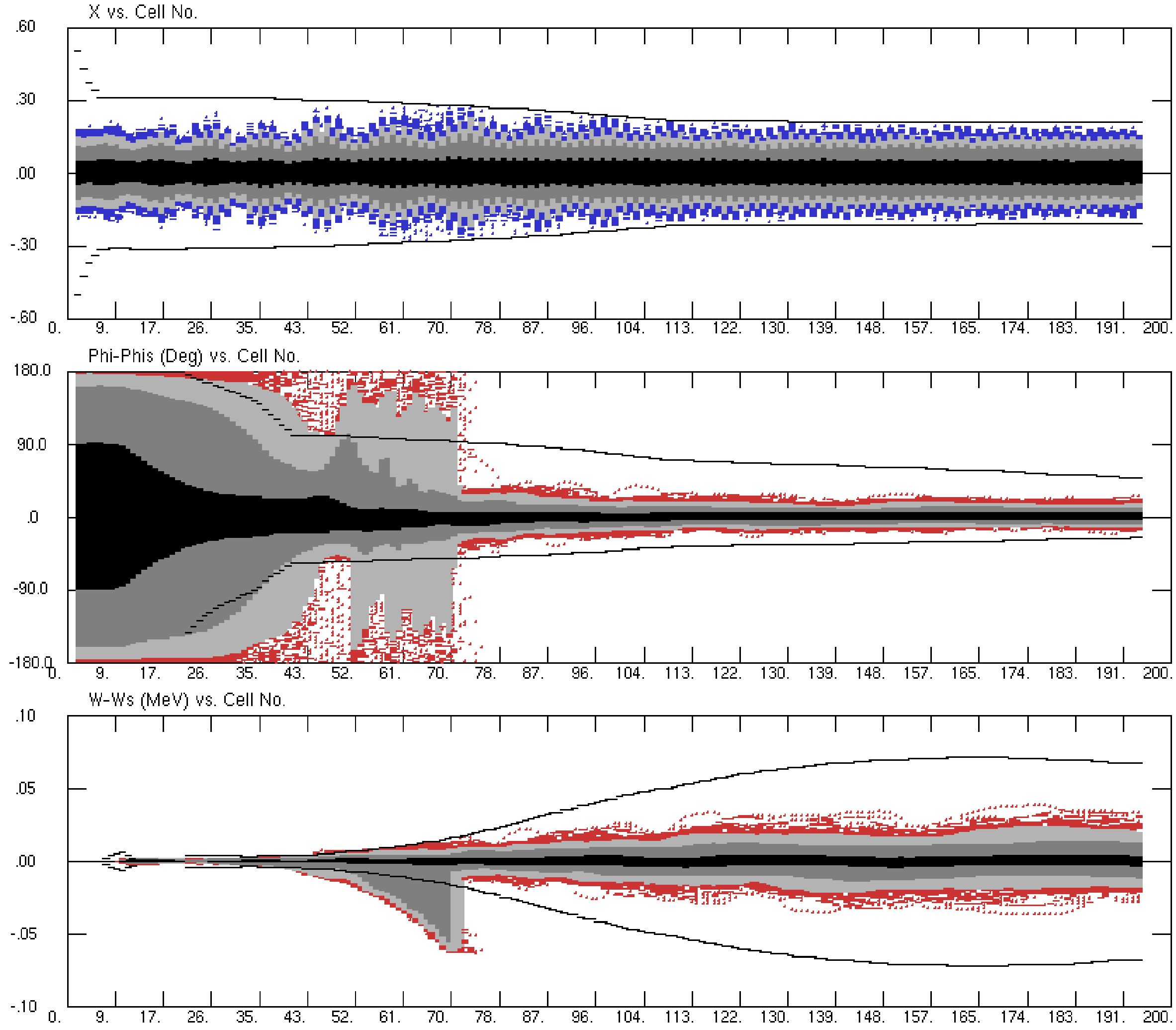
325 MHz Kick-buncher RFQ Beam Traces

The uncaptured beam, shown here eliminated at cell 72, actually continues to the end.

x vs. cell number
normalized emittance
=0.028 cm-mr

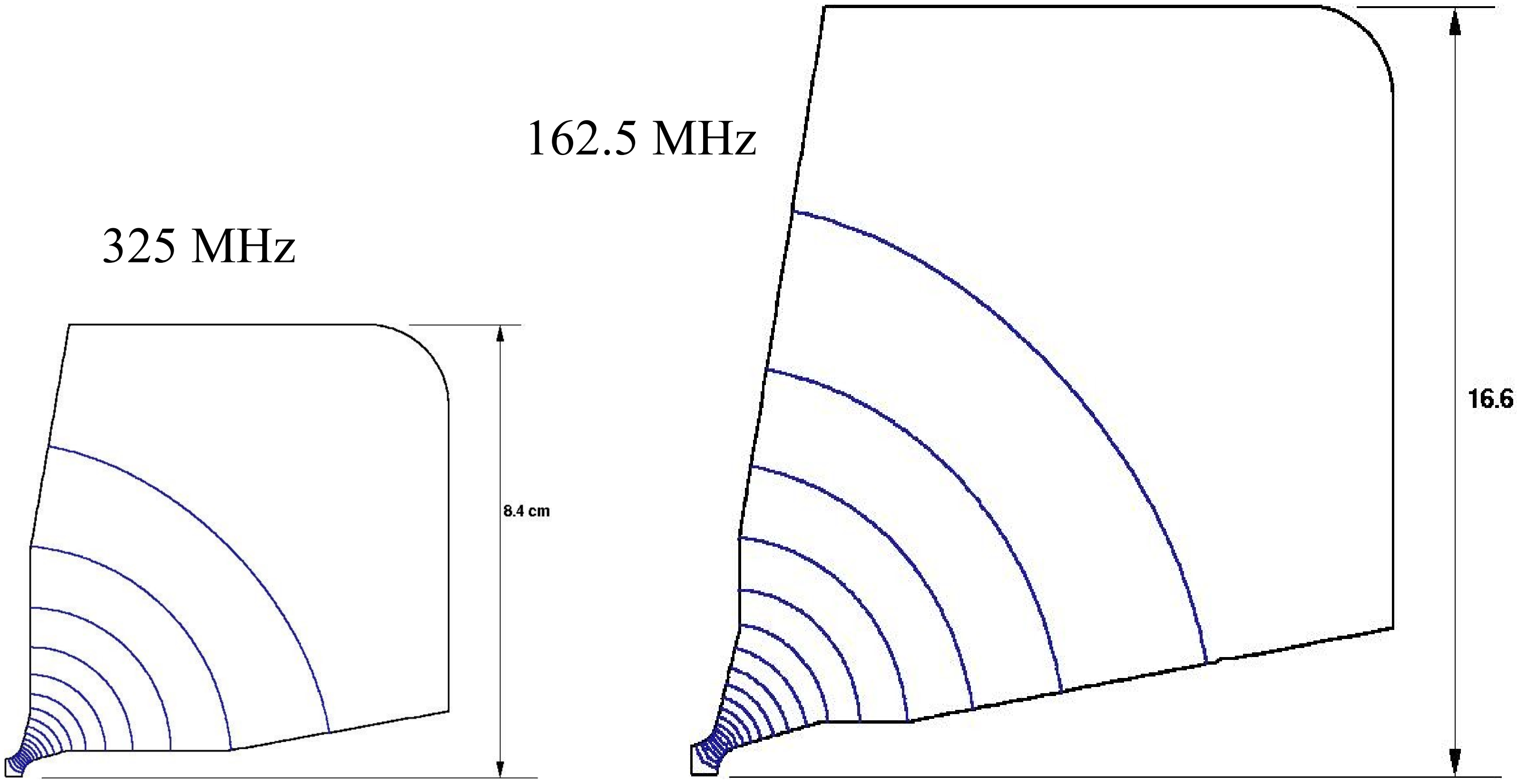
Phase vs. cell number
rms phase spread
= 6.5 deg

Energy Spread
vs cell number
rms energy spread
= 7.2 keV



RFQ Cavity Shape

The 162.5 MHz RFQ just about twice the linear size of the 325 MHz design.

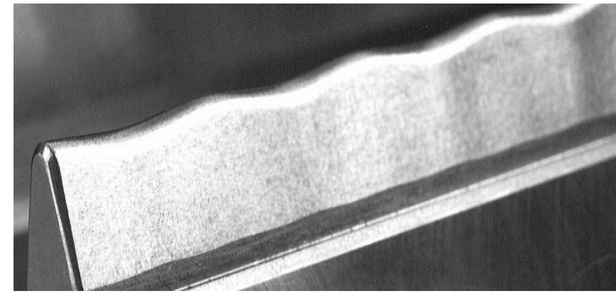


Other RFQ Design Considerations

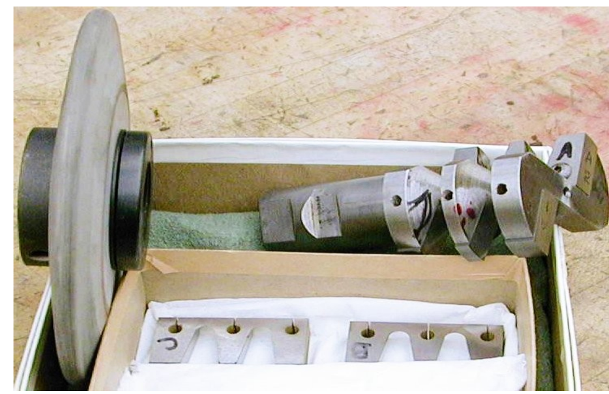
Constant parameters along the RFQ simplifies design

vane tip transverse radius

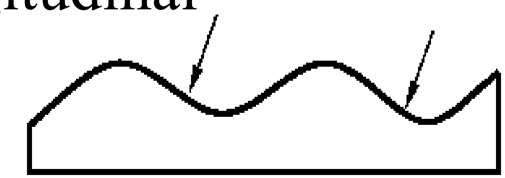
vane-vane voltage

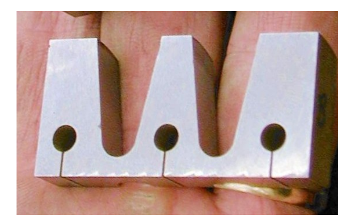


Thermal load constant along length, stabilizes field distribution.



Vane modulations cut using a constant-radius fly cutter lowers the manufacturing cost. Beam dynamics design must allow an "easy" cutter geometry for the minimum longitudinal vanetip radius parameter.





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325 or 162.5 MHz?

The power requirements are similar. The internal cavity volume of the 162.5 MHz is nearly 6 times the 325 MHz RFQ.

The one clear advantage of the 162.5 MHz RFQ is the lower wall power density and larger transverse acceptance.

Coupling RF into the 325 MHz structure may require iris couplers, which are more difficult to design and to adjust. The 162.5 MHz structure would use loop couplers. (The 402.5 MHz SNS RFQ uses loop couplers running around 400 kW per coupler at 7% duty factor.) Another LBNL project will transmit up to 60 kW CW per coupler at 187 MHz with no cooling required.

The SNS LEBT / MEBT Example

The SNS requires a 1 MHz chopper, which was distributed between the LEBT and the MEBT. (Slow LEBT chopper, and fast MEBT chopper). Arbitrary waveform chopping is required.

The 56-mA LEBT design uses electrostatic focusing, which avoids neutralization build-up time. It took some time to iron out the operational difficulties, mainly sparking damage to the chopper power supplies and safely dumping electrons from the H-minus ion source.

The 2.5 MeV MEBT uses a 1 MHz travelling wave chopper and a series of magnetic quadrupoles and 402.5 MHz rebuncher cavities to match into the following 402.5 MHz DTL.

The FNAL MEBT must filter out the low-energy drift-through beam from the RFQ away from the SSR0 cavities.

Summary

CW RFQs present unique problems of thermal management and RF power production and coupling.

New beam dynamics designs, optimized for lower-current RFQs, result in lower power requirements and lower longitudinal output emittance.

Mode stabilization may be required.

All RFQs generate a low-energy tail that must be removed ahead of superconducting structures

All this is something that LBNL can do.